Machinery Messages

Vibration analysis of reciprocating compressors

by Steven M. Schultheis, P.E.
Marketing Manager,
Reciprocating Machinery
Bently Nevada Corporation

Improvements in predictive maintenance techniques have vastly increased the reliability of rotating machinery. In the hydrocarbon processing industry, where many successful techniques were developed, the focus is now on increasing the reliability of reciprocating machinery. Reciprocating compressors in refineries and chemical plants, which were once spared, are now used to prevent bottlenecks in processes and increase production. In our present environment of global competition and cost reduction, reciprocating compressors have become critical to the process.

For many years, people in the pipeline industry have improved the performance and reliability of reciprocating compressors through performance and pulsation analysis. These techniques are now being implemented in refineries and chemical plants. However, little attempt has been made to monitor the basic mechanical characteristics of these machines. Bently Nevada has several basic techniques for measuring and analyzing vibration in reciprocating compressors that can greatly improve machine availability.

Analysis Techniques

Many people have found it difficult to analyze vibration on reciprocating machinery. The problem is that most have looked at vibration in the frequency domain, rather than in the time domain. A typical frequency spectrum from a case-mounted accelerometer is shown in Figures 1a and 1b. The data in the frequency domain is rather confusing, with multiple orders of running speed (out to 10X), along with some frequencies that don't correlate to running speed at all. What is an analyst trained in the evaluation of rotating machinery to make of all this? The secret is to view the data in the time domain, and to correlate the data with both the position of the pistons in the stroke, and the rod load curve.

Reciprocating machinery vibration analysis theory

The design philosophy for most reciprocating machines is to minimize unbalanced inertial and pressure forces, and to use the large mass of the foundation to absorb the remainder of the energy. The unbalanced inertial forces can be minimized by using counterweights, dummy crosshead weights, or simply by arranging the cylinders to balance the forces, such as in a balanced opposed design. Any malfunction that affects this balance generates running speed vibration, particularly in the crankcase, as the forces are transmitted through the main bearings to the foundation. This vibration is best detected with case-mounted transducers. Velocity transducers (including Bently Nevada's Velomitor® sensor) are preferred over accelerometers for this measurement, due to their better signal-to-noise ratio at the low running speed frequency. The vibration amplitude is very dependent on the stiffness of the machine installation (foundation, cas-

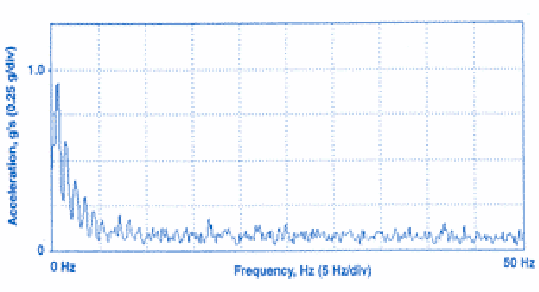

Figure 1a
Spectrum display - 0 to 50 Hz span

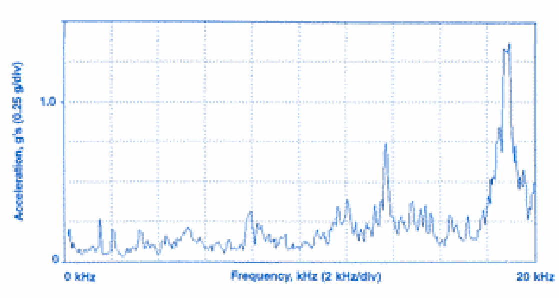

Figure 1b
Spectrum display - 0 to 20 kHz span

ing, and bearing stiffness). A very simple formula describes this:

$$\overline{R} = \overline{F} / \overline{D_S}$$

where:

$\overline{R}$ = Vibration response
$\overline{F}$ = Net periodic forcing function
$\overline{D_S}$ = Dynamic Stiffness

In absolute terms, if the periodic forcing function increases, vibration increases. Conversely, as system stiffness decreases, vibration increases. Therefore, appropriate alarm settings may depend on the stiffness of the machine, as well as on changes in the force. A field gas gathering machine, mounted on an I-beam skid in an oil field, will typically have a relatively low mounted stiffness, and, as a result, high vibration levels. Conversely, a process gas compressor in a chemical plant, solidly mounted to a foundation block and full bed grouted, should have a relatively high mounting stiffness and lower vibration levels under normal conditions.

Editor's Note: *Detailed information on Dynamic Stiffness measurements is available. Contact the Orbit editor at the phone, fax or e-mail address listed in the table of contents page of this Orbit.*

Dynamic forces in the cylinder and crosshead assembly are applied at 1X or 2X crankshaft rotation. However, under a number of failure modes, impacts may occur that excite natural frequencies of the machine structure, typically between 2 and 20 kHz. Examples are excessive clearance in the wrist pin bushing, a piston nut that has backed off, or other looseness in the running gear assembly. These failures are usually found in the crosshead and piston assembly. Due to the high frequency resonance response of the structure, crosshead and cylinder vibration can be effectively measured with accelerometers. Under normal conditions, the vibration level in gs should be very small (less than 4 to 6 g's). As impacts occur, the level increases, and the waveform will look like a classic decaying response over each stroke. A decaying response is the vibration waveform you get when you mount a transducer to a cantilevered bar, and hit it. The peak to peak amplitude starts high, and then rings down as the damping dissipates the vibration energy. Please refer to "Detecting internal looseness in a reciprocating compressor," a case history on this type of measurement in the March, 1995 issue of the Orbit.

Detecting typical malfunctions

Deteriorating foundation

As foundation bolts loosen, grouting deteriorates, or other stiffness changes occur, the operating deflection shape (relative vibration between points) of the crankcase will change. To evaluate crankcase vibration, look at time domain data and relative phase in the region of 1X and 2X running speed. This is detected by evaluating both the amplitude of the vibration and changes in relative phase between crankcase measurement points.

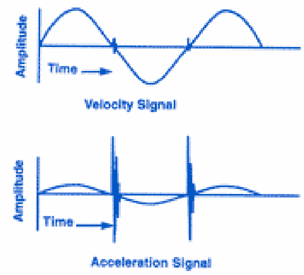

Figure 2

Typical waveform for impact events

Crosshead and distance piece malfunctions

This is the best area to see impact events that indicate malfunctions, such as excessive crosshead pin clearance, loose piston nuts, and other impact generating events. These signals are effectively measured with an accelerometer, and will typically show a decaying response over the stroke (Figure 2). Tracking the amplitude and location in the stroke of these events provides a good indication of impending problems. Also, the vibration signal from the rod drop proximity probe (Figure 3) will detect piston-related problems. Refer to the article on page 17, "The value of piston rod vibration measurements in reciprocating compressors."

Valve problems

A valve leak is denoted by high frequency vibration, a whistle caused by

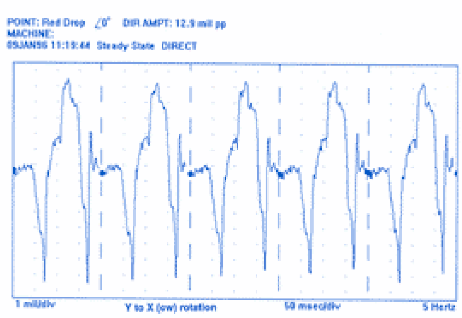

Figure 3

Timebase waveform of data acquired with a Rod Drop proximity transducer.

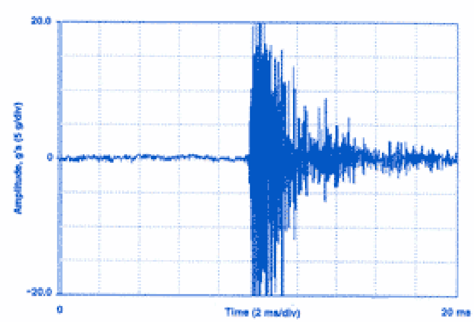

Figure 4

Timebase waveform of data from an accelerometer mounted on the valve cover of a reciprocating compressor.

gas escaping through the leaking valve. One technique used to confirm valve problems is to collect data from an accelerometer mounted on the valve cap and to evaluate the timebase waveform (Figure 4), relative to a reference that defines top dead center and bottom dead center. The extent of a valve leak can be determined both by the amplitude of the vibration and by the duration of the high frequency energy relative to the stroke. The portion of the stroke in which the whistle occurs can isolate the problem to either a suction or discharge valve.

Cylinder vibration

The vibration level of the cylinder in a plane parallel with the piston motion (often referred to as cylinder stretch motion) increases in the following situations: in the event of loose or broken attachment studs, either between the cylinder and the distance piece, the distance piece and the crosshead, or the crosshead and the frame, and when a cylinder is overloaded. The vibration occurs synchronous (1X) with crankshaft rotation and can be effectively monitored with a velocity transducer mounted on the cylinder head (Figure 5). In some installations, the transducer is mounted on the crosshead at a 45° angle in the plane of the piston motion, to detect both vertical and cylinder stretch motion with one transducer.

Crankshaft and bearing problems

Bearing faults and wear are best determined by using proximity probes to measure crankshaft displacement relative to the main bearings or by measuring bearing temperature. Under normal conditions, the path described by the shaft centerline as it vibrates (the orbit shape) is generally elliptical, and vibration amplitudes are nearly equivalent to bearing clearance, due to the rotating load vector (Figure 6). Any variance should be investigated.

Conclusion

Vibration analysis techniques can be successfully used to evaluate the condition of reciprocating machinery. Effective permanent vibration monitoring typically consists of a combination of vibration transducers. Velocity transducers are installed on the crankcase in the horizontal plane parallel to the pistons to detect changes in running speed vibration and changes in crankcase deflection. These transducers are aligned with the primary forces on the machine. Proximity probes, which measure both the position and dynamic motion of the piston rod, detect rider band wear, as well as problems that increase the piston rod vibration. Accelerometers installed on the crosshead or distance piece of each cylinder detect impact events. Accelerometers can also be used to confirm valve problems when they are temporarily installed on the valve covers. The key to analyzing these vibration signals is to evaluate the data in the time domain and to correlate the data with both the position of the pistons in the stroke, and the rod load curve.■

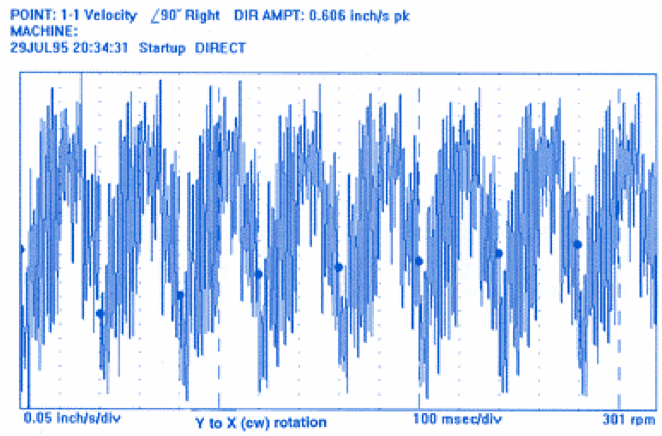

Figure 5
Timebase waveform of cylinder vibration, acquired with a velocity transducer.

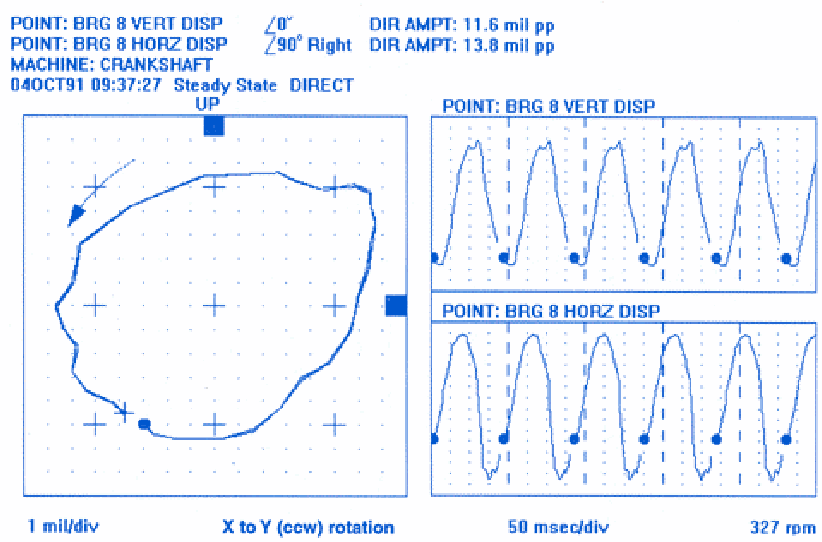

Figure 6
Orbit/timebase plot of unfiltered vibration, acquired from the crankshaft with proximity transducers.